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Trade-off analysis of ecosystem service provision in nature networks

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ABSTRACT

We propose a spatial multi-criteria decision analysis approach as a value-focused decision support tool for evaluating land use change decisions affecting multiple ecosystem services. In an empirical case study concerned with creating a robust and interconnected network of natural areas in a Danish municipality, we first conduct a biophysical and economic baseline mapping of ecosystem services. We then construct a spatially explicit multi-criteria decision analysis model which is utilized to identify candidate areas for inclusion in the network. We define a base scenario for future land use in the area, where all criteria have equal weight, and assess the outcome in terms of welfare economic benefits of ecosystem services and opportunity cost of reducing forest and agricultural production. As weights in multi-criteria analysis is innately a subjective task, we conduct a sensitivity analysis using four corner solution scenarios. The analyses illustrate the possible range of impacts and highlight the specific trade-offs between different ecosystem services. We argue that a multi-criteria decision analysis approach will help inform decision makers in a structured and informative way when considering future land use changes.

1. Introduction

The EU Biodiversity Strategy 2020 addresses maintenance and improvement of ecosystems and their services, calling for significantly increased focus and frequent evaluations of these from a biophysical point of view. Even more ambitious is the goal of integrating economic values of ecosystem services into national and EU accounting and reporting systems by 2020 (Maes et al., 2013). Preliminary mapping and evaluation have already been conducted at European level, and it is clear that large data deficiencies prevent full economic evaluation (Bateman et al., 2011). However, a number of assessments are useful references such as the Millennium Ecosystems Assessment (World Resources Institute, 2005), The Economics of Ecosystems and Biodiversity (Sukhdev et al., 2010), and the UK National Ecosystem Assessment (Watson et al., 2011). Valuation studies are abundant but still context dependent with respect to assigning monetary values to ecosystem services. Thus complete and comprehensive cost-benefit analyses for land use changes remains challenging.

In Denmark, the Danish Nature and Agriculture Commission (NAC, 2013) published a number of recommendations on how the structural, economic and environmental challenges of the current land use in Denmark can be addressed. The future implementation of NAC's recommendations may include the establishment of a green nature network is to create a more robust and interconnected natural environment for improved biodiversity protection.

Environmental decision making in such cases is in general challenged by unclear and sometimes internally incompatible objectives. Furthermore, knowledge about the suite of potential alternatives and their outcomes is often incomplete among decision makers, in particular when the outcome depends on spatial and temporal dynamics. Multi-criteria decision analysis and structured decision making may assist in evaluating what land areas to designate for nature protection when faced with such multiple objectives (Gregory et al., 2012). This study presents an application of a multi-criteria approach to prioritize future land use in a robust and coherent green biodiversity network based on quantitative performance measures of ecosystem services within the Haderslev Municipality in Denmark. It illustrates the aspects of biophysical and welfare economic trade-offs between ecosystem services and shows the applicability of spatial multicriteria evaluation tools for the mapping and assessing of ecosystem services for decision making.

2. Case study area

All municipalities in Denmark with the assistance of the Danish Nature Agency are required to appoint areas suitable to become part of a national nature network (Ministry of Environment, 2014). Haderslev Municipality in the South Eastern part of the mainland Jutland was chosen as an illustrative case area, as it contains a wide variety of ecosystems in agricultural land and forests as well as coastline and

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Fig. 1. Location of the case area Haderslev Municipality in Denmark.

cities. Out of a total surface area of 81,370 ha, agriculture accounts for 56,951 ha or approx. 70% of the Municipality's area, higher than the country average of about 62%. Forests account for 9407 ha or 11.6%, somewhat below the country average (University of Twente, 2013). The remaining areas are either open nature, for example heathland, especially in the western part, and towns and roads (Fig. 1).

In this paper, the effects of three conservation measures are analyzed:

1) Afforestation of agricultural land and conversion of managed forests into un-managed forest set aside for biodiversity protection
2) Conversion of agricultural land into extensive grassland

The conservation actions in forest include an immediate stop of forestry intervention and drainage in broadleaved forests, allowing for conversion of commercial production forests into unmanaged forests with natural hydrology. Unmanaged forests will secure continuity of forest cover and gradually increase the amount of dead wood, as well as variation and dynamics with respect to tree species, age structure and density. Reduced forest interventions will benefit a range of species including saproxylic insects and hole-dwelling birds as well as epiphytes and fungi (Friedel et al., 2006; Ódor et al., 2006; Brunet et al., 2010; Müller 2010; Müller et al., 2013; Lassauce et al., 2011). The conversion of agricultural land into grassland includes: (1) Maintenance of existing natural areas, (2) increased area (expanding the current natural areas), and (3) reduction of nutrient pollution. Maintenance includes grazing, harvest of hay and/or clearing of scrub, to prevent invasion by shrubs and trees. Open natural grassland areas in Denmark are typically very fragmented, and increasing the area is believed to benefit the survival of species through increased ability to maintain viable (meta) populations (Rouget et al., 2006). These two measures are selected to represent a high focus on protecting nature values in both open country and forests and can be considered two extreme measures.

3. Methodological approach

Making decisions about alternative actions affecting the environment requires not only careful thinking about the potential outcomes, but also conceptual thinking about whether the decision process should be alternative-focused or value-focused (Keeney, 1996). The alternative-focused approach begins with development of a limited set of alternatives, followed by the specification of values and criteria and then concludes with evaluation and recommendation of one alternative among those selected for evaluation. The risk in this approach is that the decision maker does not map the entire relevant set of alternatives and criteria. Additionally, the analyst and/or decision maker may be biased by beliefs, motivation, and prior experience, thus being in danger of overlooking less obvious alternatives (Kahneman, 2011). Oppositely, value-focused thinking initiates the decision process by mapping the values and objectives prior to considering any alternatives and the use a structured procedure for generating alternatives. This process has in recent years in environmental planning become known as structured environmental decision making (Gregory and Long, 2009; Gregory et al., 2012).

The steps in structured decision making should at least consider what objectives and performance measures will be used to identify and evaluate the alternatives, the expected consequences of these actions or strategies, uncertainties and key trade-offs, implementation and learning (Gregory et al., 2012). Decision problems where alternatives need to be developed and eventually evaluated are suitable for a value-focused approach. This study applies a value-focused structured decision making approach in the form of a spatial multi-criteria decision analysis model.

3.1. Spatial multi-criteria decision analysis

Multi-criteria decision analysis (MCDA) is a widely used method within the frame of natural resource management (Mendoza and Martins, 2006). One obvious advantage of the method is its structured and rational approach to comprehensively deal with multi-functionality and multiple stakeholders. The MCDA further has a great potential as a decision and communication platform facilitating the handling of factors not presented in similar units. Where cost-benefit analysis embeds the challenge of converting all inputs and outputs into a single currency, the MCDA includes a similar, inherent problem of establishing precise weights among criteria (Bogetoft and Pruzan, 1997).

The MCDA used in this paper follows the general approach of finding a decision which maximizes the objective function given a feasible set of alternatives (Bogetoft and Pruzan, 1997). An objective function $v(x)$ is maximized with respect to each of the different alternatives (x) within the set of feasible alternatives (X):

$$\begin{aligned} &\text{Max } v(x) \\ &\quad \text{s.t.} \\ &\quad x \, \varepsilon \, X \end{aligned} \tag{1}$$

In dealing with land use change it is beneficial to apply a spatial GIS-based model (Mendoza and Martins, 2006). The spatial MCDA model allows for area specific characteristics and requires data on criterion values for every geographical location in its feasible alternatives. The analysis then relies on the inputs in the form of geographically positioned data, the decision maker's preferences for the inputs and their relative importance, i.e. the weights, and, finally, functions for how the inputs are to be evaluated, also referred to as score functions. These functions ensure that all data are standardized into one-dimensional values. If the spatial location of the relevant criteria is in place, the spatial MCDA model can assist in making better solutions that would otherwise be difficult to identify due to the complexity of the problem (Malczewski, 1999).

To apply a spatial MCDA model validly it is important to be accurate in formulating the problem at hand in a way such that the relevant criteria and attributes can be fed into the model. Setting up a goal, i.e. the objective function in (1), is determining for the underlying criteria. The criteria should be defined in a way that describes the goal as comprehensively as possible. However, data availability can constrain the selection of criteria, which can lead to a simplification of the problem at hand (Van Herwijnen, 1999; Malczewski, 1999). Criteria are most often organized in a number of attributes. In a spatial MCDA these attributes are various data layers or maps all covering the geographical range in question and the layers are then added on top of each other (Sharifi and Rodriguez, 2002). Aligning data layers in raster or polygon format allows for evaluating values of the respective maps relative to each other. Using scaling functions to standardize all values between 0 and 1 facilitates computation of a total score for each given geographical area. In relation to the stated goal, each criteria and attribute is defined as a benefit, a cost, or a combination indicating the sign and thus influence on the total score (Malczewski, 1999).

When defining attributes one tries to follow an objective line of thought, and the attributes are based on available data and often include expert opinion (Malczewski, 1999), though true objectivity cannot fully be secured. Criteria are of a more subjective matter as the decision maker can decide to add or omit them based on his objective whereas the weighting of attributes under a criterion often is determined early in the model design phase as these both reflect decision maker's preferences and expert opinion on functional relations. To be able to compare scenarios etc. of model iterations these weights are rarely changed later on in the process. Subjectivity is thus a factor that need to be managed; often by involving a range of stake-holders to evaluate criteria (Malczewski, 1999).

Methods for assessing criteria and attribute weights vary but all seek to express the importance of each attribute to the goal (Malczewski, 1999). The weights assigned are to be thought of not as much as a direct ranking of importance, but as an expression of how much a change from the minimum to the maximum value of say an attribute matters compared to the same change in another attribute.

Having decided upon criteria, assigned attributes and weights, standardized these, and set alternative states for each area, the model is ready to be run in order to be able to make a decision in adherence to the initially stated goal. Simple additive weighting methods also named weighted linear combination (WLC) methods are the most commonly used and can be formulated as:

$$A_j = \sum_j w_j * x_{ij} \quad \text{s.t.} \quad 1 \geq w_j \geq 0 \text{ and } \sum_{j=1}^{m} w_j = 1 \tag{2}$$

where A_j is the overall score of the alternative relying on the weight w_j and the score x_{ij} of the i'th alternative with respect to the j'th attribute. Usually the weights are normalized to lie between 0 and 1 and sum to 1 as presented above. The alternatives with the highest score are the most suitable for reaching the goal (Mendoza and Martins, 2006).

3.2. Design vs. choice phase

As the goal of the model in this particular case is to select a network of areas and not one particular location for say establishing a conservation area the usage of spatial MCDA in this paper differs slightly from classic spatial resource allocation problems. Having to choose a single spot for a large investment, the spatial MCDA will find a number of suitable areas. These are then deemed equally suited and named alternatives, which then in turn can be compared using non-spatial factors such as tax rate, economic indices etc. Having performed this analysis, a single alternative can be selected and the investment made.

In this paper, not a single spot, but a nature network is the goal and the method as such is equal to the above in finding suitable areas. However, the analysis then needs to go no further as all area pixels have been assigned a final score and have thus been ranked in the suitability process. Depending on the political will and other non-spatial factors such as the value of externalities like carbon etc., the extent of the network is determined by the decision maker, but the pixel of highest value will always be part of the network. Thus, in our problem if the question comes down to choosing between a network of 10, 20, or 30.000 ha, the most suitable 10.000 ha will in all cases be selected etc.

Based on selected criteria the design phase seeks to examine the suitability of each pixel towards the goal and thus generates suitability maps showing degrees of suitability in relevant intervals or as an interactive map. The design phase only incorporates spatial data inputs. The suitability maps are based on the following model:

$$\hat{X}_i = \sum_{j=1}^{m} w_j * x_{ij} \quad s.t. \quad 1 \geq w_j \geq 0 \text{ and } \sum_{j=1}^{m} w_j = 1 \tag{3}$$

where $\hat{X}_i$ is the suitability degree of the pixel i and w_j is the weight assigned to criterion j that has a score value of x_i. The weights are standardized to values between 0 and 1 and the sum of the weights adds up to 1 (Malczewski, 1999).

4. Materials and model design

Based on problem scoping and identification of objectives and attributes during several interviews with decision makers at The Danish Nature Agency and Haderslev Municipality the following seven objectives/criteria in the spatial MCDA model: 1) increase nature values, 2) increase ground water protection, 3) increase recreational values, 4) reduce opportunity cost from economic losses (value of lost agricultural and forest production), 5) include relevant soil characteristics, 6) enhance location in Administration zones (afforestation and hydrological areas), and 7) promote location in areas facing risk of being affected by sea level rise from climate change. The attributes that make up each of these criteria in the spatial MCDA model are map layers from various sources and in various formats and will be presented in detail in the following. These layers are initially aligned using the software ArcMap 10.1 (ESRI, 2012). Maps are geographically aligned in a raster grid consisting of 25×25 m pixels. This size proved suitable for land use change analyses providing a high level of detail while maintaining variability amongst pixels. Raster data is then exported to the software ILWIS.[1] Standardization of attribute levels to the interval 0–1 is specified in ILWIS as linear or stepwise linear. Most attributes are dummy variables and thus appear as either 0 or 1.

For our base scenario, weighting of criteria are set to be equal to unity. The choice of equal weights is chosen as a sort of neutral stance on any political agendas implying that all criteria are equally important.[2] The sensitivity or trade off analysis further explores the implications of changing weights among criteria. Four potential stakeholder views representing extreme or corner solutions are analyzed. This serves to illustrate the systematic method and transparency of the spatial MCDA model.

Using ILWIS we calculate the spatial MCDA total scores per pixel which provides a mapping of where the highest potential to society is located when taking all attributes into account. The composite map

[1] Integrated Land and Water Information System (University of Twente, 2013).

[2] We do acknowledge that using equal weights is not as such neutral but rather represents what might simply be considered a political/subjective stance of all criteria being equally important. In fact, the concept of pure neutrality in relation to trade-offs does not exist in MCDA nor in any other decision support method based on social welfare for that matter.

Table 1
Decision tree for the base scenario used in ILWIS 3.8.3.

Criterion	Weight	Attribute	Weight	Impact on criterion
Nature value	0.14	High Nature Value Index (continuous 0–10)	0.33	Positive
		Forests (dummy 0–1)	0.33	Positive
		Protected areas (dummy 0–1)	0.33	Positive
Ground water	0.14	Nitrate sensitive areas (dummy 0–1)	0.33	Positive
		Special ground water interests	0.33	Positive
		Nitrate target areas (dummy 0–1)	0.33	Positive
Recreation	0.14	*Beaches* (dummy 0–1)	0.14	Positive
		Leisure (dummy 0–1)	0.14	Positive
		Marinas (dummy 0–1)	0.14	Positive
		Shelters (dummy 0–1)	0.14	Positive
		Rivers (dummy 0–1)	0.14	Positive
		Summer houses (dummy 0–1)	0.14	Positive
		Cities (dummy 0–1)	0.14	Positive
Economics	0.14	Resource rent (continous)	1.00	Negative
Soil	0.14	Retention coefficient (continous)	0.50	Negative
		Low lying areas (dummy 0–1)	0.50	Positive
Administrative Zones	0.14	Reforestation areas (dummy 0–1) Hydrology projects (dummy 0–1)	0.50 0.50	Positive Positive
Climate change	0.14	Sea level rise 2 m (dummy 0–1)	1.00	Positive

thus shows a ranking of each land pixel according to where changing land use would be most attractive as assessed by the attributes. The analysis is based on the total scores. Combining spatial location of pixels in descending order of total score with attributes of the same pixels, actual values allows for a precise calculation of consequences. This is done using the “Cross” function in ILWIS generating a spreadsheet of total scores with corresponding selected attribute values. As ILWIS does not allow for manual calculation the subsequent data manipulation is performed in Microsoft Excel. This includes summing of economic costs and other scores across pixels and proportion calculations of the total possible score. These results are the focus in Section 5.

4.1. Base scenario decision tree

Table 1 shows the decision tree for the base scenario as applied in ILWIS 3.8.3. The goal of the base scenario is to select a robust and interconnected nature network. The seven criteria are presented with their equal weights of 1/7. Each criterion is then divided further into attributes with respective weights, which will be described below. Finally, the last column indicates the sign of the attribute towards the goal i.e. whether is it a benefit or a cost to society.

4.2. Nature values

To factor in biodiversity, spatial indicators are put into effect using the so-called “High Nature Value” (HNV) Farming Index developed by Ejrnæs et al. (2012). The HNV index is created to assess nature values in the Danish open farmland. It contains 14 indicators of topography and habitats, presence of red listed species, forest proximity, nature management areas, and other aspects of significance for an area's value and potential for biodiversity support. The fulfillment of each indicator gives a score of 1. The maximum HNV index score is 14 and indicates a very high nature content/potential (Ejrnæs et al., 2012). We apply a threshold such that HNV values above 10 in a given pixel result in a score of 1. With the HNV Index covering open farmland, forests and protected areas are included to factor in remaining natural values. Since a classification similar to the HNV index was not available for forests, these are set to indicate a very high natural value that is 10 in line with the HNV threshold. With the assigned equal weights to this layer this means a disclosed score of 0.33 as seen in Table 1. Cells in forested areas are thus also assigned a score of 0.33 indicating high nature value and potential. Protected areas can overlap the previous two layers. A cell in a protected area adds 0.33 to the score but if the layers overlap e.g. forests, the cell can reach of score of 0.67. Heathland which is neither agricultural land nor forest is assigned a score of 0.33. The nature value criterion in Table 1 thus consists of three attributes or layers. This is a simplified approach to estimate the natural value of the landscape, but it allows for counting in all nature values in Haderslev Municipality.

4.3. Ground water

With respect to ground water interests, three different GIS layers from Denmark's Environment Portal (Denmark's Environment Portal, 2014) have been applied: nitrate sensitive areas, special ground water interests, and nitrate target areas. Nitrate sensitive areas lie scattered across the Haderslev Municipality, and parts of these and a number of smaller areas are also classified as nitrate target areas. A nature network placed here would reduce the risk of nitrate leaching and benefit ground water protection. Most of the case area is classified as being of special interests for ground water protection. Only the city center of Haderslev does not hold this classification. The three layers are seen in Table 1 under the ground water criterion with their equal weights of 1/3.

4.4. Recreation

To incorporate the importance of recreational objectives, a number of areas and sites have, for the purpose of the model, been assigned buffer zones to represent a spatial importance. The selection of the model then effectively factors in recreation by selecting areas, where establishing new natural areas is expected to have a great social value. The relevant sites and assigned buffer zones can be seen in Table 2.

Table 2
Buffer zones for recreational purposes around selected areas.

Site (buffer zone)	
Beaches (200 m)	Shelters (500 m)
Leisure areas (200 m)	Rivers (250 m)
Marinas (500 m)	Summer houses (500 m)
Cities (500 m)	

Their equal weights of 1/7 are seen in Table 1 under the recreation criterion.

4.5. Economic losses from nature protection

The country side of Haderslev Municipality is dominated by agriculture. The resource rent for agricultural land represents the annual net profits from crop production. It is assessed as the difference between the crop sales value and the total costs incurred in cultivating it including seeds, fertilizer, chemicals, wages (incl. the owners'), and depreciations and interest payments on machines and equipment. In theory, the resource rent corresponds to the lease rent of a plot of land with a given production potential. Resource rent calculations are mainly based on budget calculations from the Knowledge Centre for Agriculture (Videnscenter for Landbrug, 2013). The conversion of agricultural land into nature areas implies a loss of the resource rent. The considerable EU support to agriculture, the Single Farm Payment is, however, not included in the resource rent loss (Estimated to 2.600 DKK per hectare per year; additions for cattle, milk, and sugar production etc. is not accounted for (Dubgaard et al., 2013)). The cultivation of fields is not required for receiving Single Farm Payment; however, fields must be kept in good agricultural and environmental conditions, which involve annual cutting or close-cropped grass. For low lying areas it means drainage enabling cutting or close-cropping in summer time. Converting into nature leaving the area to its natural succession means that the conditions are not full filled, and the Single Farm Payment is foregone resulting in losses additional to the resource rent loss. From the Danish society's point of view, the welfare economic loss, however, is only the 55% financed by the EU (Dubgaard et al., 2013), as the rest is a transfer from society to the farmer.

The conversion into unmanaged forest also implies surrendering Single Farm Payment which is expected to have a higher welfare economic effect also as the total Single Farm Payments allocated to Denmark could then be reduced at the next EU budget allocation.

For proper welfare economic analysis all prices are multiplied by a net-tax factor of 1.325 providing the welfare economic loss as perceived by consumers (Danish Energy Agency, 2014).

We present both annual private economic losses and annual welfare economic losses. Losses to the farmer can be calculated as the net present value of a constant perpetuity of the resource rent loss using an applicable discount rate.

As no analysis of hydrological consequences exists for the drinking water extraction as a consequence of land use change in Haderslev Municipality, it is not included in the welfare economic assessment in this paper. The resource rent figure is thus the sole attribute of the economics criterion in Table 1. The loss of resource rent to society feeds into the spatial MCDA model as an attribute with a negative impact.

4.6. Soil, administrative zones, climate change

Soil characteristics enter the model in two ways. Firstly by the so-called retention coefficient, which is a measure of the soil's ability to retain nitrate and thus reduce leakage to water bodies. It appears as a cost which means the model is asked to select areas with little retention capability firstly. Secondly, low lying areas, which often are difficult to drain, can function as buffer zones reducing leaching to open water and are of marginal agricultural value is an attribute here (DCE, 2008). Administrative zones cover areas that the Municipality has already appointed as reforestation areas or where hydrology projects are ongoing (Denmark's Environment Portal, 2014). Hence, these are obvious to include in a nature network and represent a restriction in the data.

Climate change is expected to increase mean sea levels. The Danish Geodata Institute estimates a 1 m sea level rise over the next 100 years. Thus, areas which are expected to be flooded in the future are removed before model iteration. However, the current areas between 1 and 2 m above sea level along the coasts are hence expected to hold important coastal ecosystems in the future are therefore included with this coding (Danish Geodata Agency, 2013). These areas therefore appear as a positive impact on the model. These three criteria play a role in the selection of a nature network but will not as such explicitly affect the results and thus remain underlying features of the model.

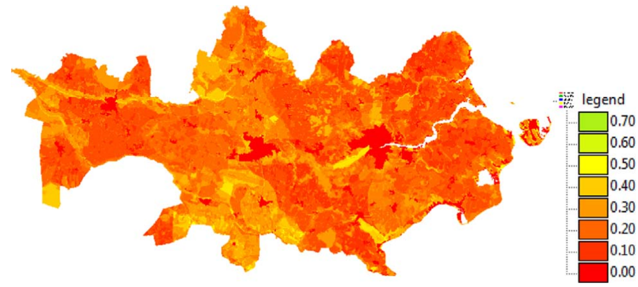

Fig. 2. Composite score map of the base scenario model with legend indicating suitability scores. High scores are shown with bright yellow colors indicating areas with the highest potential for a nature network.

5. Results

5.1. Base scenario – composite score map

In Fig. 2 the composite score map of the base scenario is presented. Given the applied data layers, score functions and the chosen equal weights presented in Table 1, Fig. 2 identifies the areas with the highest current score values and consequently the greatest potential for creating a robust and interconnected nature network in Haderslev Municipality. The bright yellow/green areas are of greatest interest, i.e. these are the areas that should be set aside for nature protection, whereas the red areas have little interest in this context. The yellow areas are mostly forests, protected and low lying areas as well as narrow strips along water ways. One cannot immediately provide a common characteristic of the orange colored areas as there are so many attributes in play, however, the red colored areas are cities and other fortified areas with no interest in this particular case.

5.1.1. Consequences for nature, ground water, and recreation

The effects on biodiversity, ground water, and recreation are in this paper presented as a proportion of the total possible score. Fig. 3 shows the percentage proportion of total possible scores for the three criteria on the y-axis. The axis is the percentagewise area of Haderslev Municipality selected for the nature network. For example, selecting the best suited 10% of the Municipality area, i.e. the 10% of the area achieving the highest composite scores, assures protection of 25% of all nature values and ground water interests; furthermore, 25% of the preferred recreational areas are secured. Interestingly, Fig. 3 reveals that a drastic increase in nature value proportion occurs if increasing the area set aside for nature protection a single percentage point from

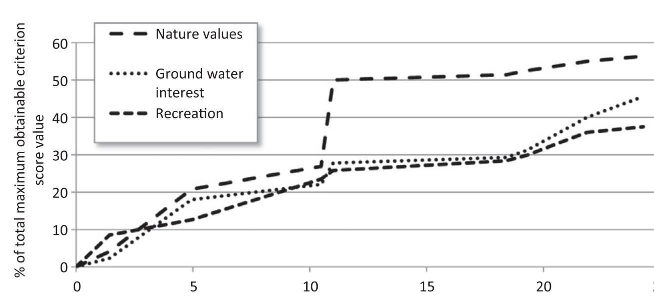

Fig. 3. Values of nature, ground water, and recreation secured by setting aside increasing areas for nature protection.

10% to 11%. This is because including this extra percentage primarily means adding in some unmanaged and protected forest areas which score particularly high on the nature value criteria. Increasing selection by one percentage point in this case means doubling the secured nature values, which amount to half the total scores of nature values in the Municipality. The reason why this major increase in nature value occurs here and not before, as could be expected, is related to the choice of equal weights of the criteria and the many other factors involved in the multicriteria decision. While these areas do have a high nature value, they also have a high resource rent meaning they are expensive to exempt from production, which affects their overall score negatively. Furthermore, other areas selected before might have a series of high scores on other criteria surpassing the scores of the high nature value. Increasing from 11% to 18% area selection has little additional effect one any of these three criteria, but thereafter ground water interest increases steeply followed by increases in recreation and less prominently nature values. Again, the aggregation of multiple criteria dimension distorts the picture of a smooth curve for each of the underlying criteria. Fig. 3 is valuable in illustrating the inclusion of underlying criteria into the area selection and understanding the complex trade-off analysis performed by the spatial MCDA model which cannot be understood independently from the full model of Table 1.

5.1.2. Economic consequences

Fig. 4 illustrates the economics costs associated with setting aside a given percentage of the area for either unmanaged forest or extensive grazing. It can be seen that conversion of agricultural land into new unmanaged forest areas has the lowest farm economic costs in any case, but with the highest welfare economic costs which is due to the issues of the Single Farm Payment previously described. All trajectories follow a linear trend with a minor kink at 11% area selection and with a steeper climb from 19% area selection and onwards, indicating that the marginal cost of setting aside more land for nature protection purposes will be increasing. Setting aside 11% of the area for these purposes, the welfare economic costs are estimated to be around 20 million DKK per year and around 13 million DKK per year in farm economic terms.

5.2. The base scenario's spatial lay-out

As an example, Fig. 5 shows the location of an 11% selection as light green areas representing a nature network in Haderslev Municipality. The selected areas generally appear clustered along streams, wetland and, high nature value areas. The map shows the nature network trailing rivers in the western part but also containing small and large areas scattered across the Municipality. Thus, this model selection to some extend corresponds to the stated criteria when designing the model for more interconnected and robust nature. However, still a large number of small plots stand alone and it could be argued that light green areas are still too fragmented to represent a truly robust network. Several options arise for dealing with this issue; one would be to remove all the independent little plots and perhaps re-selecting a larger area adjacent to the others to keep the total selection and costs the same. In the following, sensitivity analyses are performed to disclose the importance of the criteria weights assigned for the resulting alternative and to support the uncovering of possible alternative solutions.

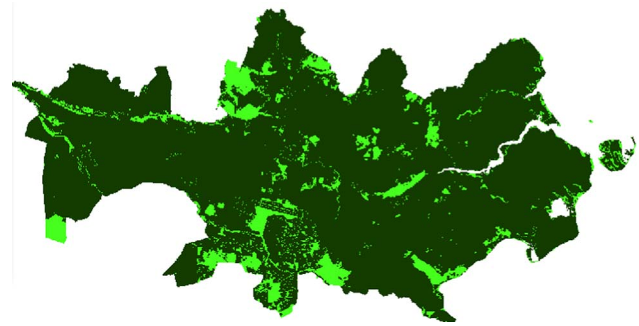

Fig. 5. Nature network in the base scenario based on a selection of 11% of total area by the MCDA model. Light green areas illustrate the areas set aside for nature protection.

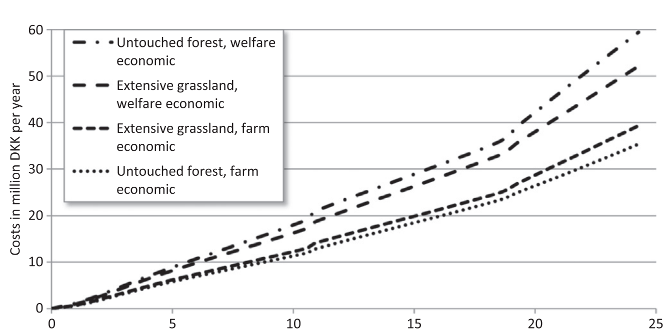

Fig. 4. Welfare and farm economic losses associated with converting increasing areas of agricultural land into unmanaged forest or extensive grassland.

5.3. Sensitivity analyses

The base scenario of 11% area selection examined above is the result of a set of weights assigned to the criteria and attributes of the model. The chosen set of equal weights is just one choice out of many possible alternatives. Some might find that nature conservation or climate change mitigation are more important criteria and assign higher weights to these criteria. Others might focus on the economic losses and try to minimize these, while still implementing conservation measures to some degree. In short, countless weighing options exist which ultimately rely on the decision makers (Rodríguez et al., 2006, McShane et al., 2011).

To illustrate how sensitive the area selection is to the weights chosen and to illustrate the full space of outcomes of these trade-offs further, the spatial MCDA model is reiterated with four different sets of weights that each are intended to illustrate corner solutions where a single criterion is given full priority. Firstly, Nature Values was assigned a weight of 1 and all other criteria a weight of 0. That is, Nature Values maximized at any given area selection assuring as much nature as possible regardless of the consequences for other criteria. A similar procedure is applied for maximizing ground water and recreation, respectively. Lastly, the economic costs were given full priority, essentially implying that the areas selected are simply the ones with the lowest economic opportunity costs.

5.3.1. Maximizing nature value scores

Fig. 6 shows the proportion of nature values included in the selection trailing up to 25% of total land area in Haderslev

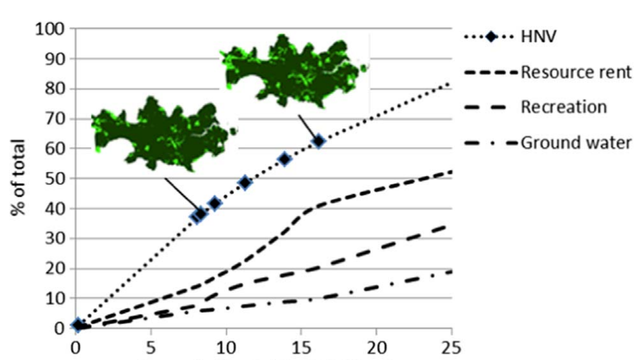

Fig. 6. Maximizing HNV.

Municipality when focusing on placing a nature network where nature values are the highest priority. This is evident from the graph depicting HNV, as a 10% area selection includes around 45% of all HNV points. At a 25% area selection, more than 80% of all HNV points are included. Diminishing returns on the graph illustrates that the model have selected high value areas first. More interesting to observe are the consequences for the other indicators resulting from maximizing HNV: in the base scenario, a 25% area selection secured around 55% of all ground water interests, whereas selecting 25% of the area based on maximizing HNV secures less than 20%. Recreation on the other hand is at a comparable level to the previous scenario. Significant is also the shape of the resource rent curve showing uneven distribution of marginal losses as area selection grows. However, total costs in this scenario amount to over 50 million DKK per year (farm economic) compared to less than 40 million DKK in the base scenario. Nature conservation as sole purpose thus effectively protects nature, but must be evaluated against the additional costs incurred, both the resource rent and the losses in other services. With regard to robustness and interconnectedness of the nature network this iteration is quite similar to the base case using equal weights as connectivity is not explicitly rewarded in the model.

5.3.2. Maximizing ground water interest scores

Fig. 7 illustrates that maximizing ground water interests yields a similar curve for this criterion as for nature values in Fig. 6, securing around 75% of all ground water interests in the area municipality by setting aside 25% of the total area. However, the consequences for the three other criteria are more pronounced than when maximizing nature values. Only 20% of nature values are now protected by the chosen set aside area and far less than 10% of recreational interests are secured in this case. Also the economic consequences are severe with an annual cost of more than 65 million DKK (farm economic). On top of large economic effects, it is evident that a negative correlation exists between ground water interest and both recreation and nature values. The maps show very different spatial patterns of the selected areas than when maximizing nature values in Fig. 6.

5.3.3. Maximizing recreation scores

Maximizing for recreation, the graphs in Fig. 8 appear different from those in Figs. 6 and 7. As the potential recreational areas defined in the data cover just about 8% of the total land area in the municipality, all recreational areas are protected with an area selection of roughly 8%. The maps show the importance of recreational opportunities in close proximity to cities and villages, around water ways, and in coastal regions. Ground water interests show negative correlation with recreation, whereas nature values again show a zero correlation with around 13% included at the 8% area selection. The buffer zones around rivers provide some network patterns, however robustness is less obvious in this instance. Resource rent loss shows similar patterns as on the previous graphs with costs incurred of between 15 and 20 million DKK (farm economic) annually. This relates to the somewhat uniform pattern of resource rent found throughout the Municipality with two broad categories of sandy and clay soils in the West and East, respectively. However, there is not enough local variability except on individual field level to alter the resource rent loss.

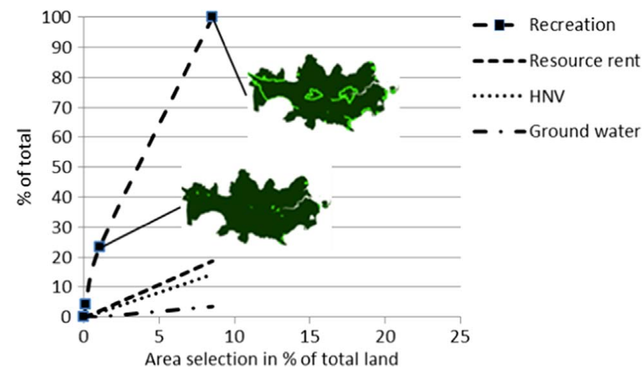

Fig. 8. Maximizing recreation scores.

5.3.4. Minimizing economic resource rent loss scores

Fig. 9 presents the results associated with minimizing resource rent loss, i.e. selecting the least valuable fields first. A striking finding is the possibility to be able to convert more than 15% of the municipality areas into nature at no apparent cost and 25% at less than 15 million DKK per year; far less than in any of the other scenarios. This is due to the specific selection of low-profitable areas such as grazing and grass covered areas that are not considered to generate any land rent. Interestingly, using this criterion for selection of areas to set aside, the recreational interests is protected similarly to the base scenario. Nature values are generally much lower in this scenario, but from around 21% selection they increase steeply to almost 40% of the total at a 25% area. Ground water interest areas are only protected at about half the amount realized in the base scenario, but higher than in the nature value and recreation maximizing scenarios. It is obvious that considerable interests of all three criteria could be included in a given selection in the scenario at a 0 or significantly lower cost than any other scenario. The major difference compared to areas selected under other criteria is the spatial pattern as shown in the maps in Fig. 9. The areas are generally small and dispersed throughout the Municipality with few large robust areas and hardly any interconnectedness.

6. Discussion

The systematic approach and transparency in revealing a vast array of possible combinations, makes the spatial MCDA model particularly valuable for identifying optimal spatial networks. Our results confirm that sensitivity analyses are crucial in disclosing the positive and negative impacts in the range of possible scenarios (Rodríguez et al.,

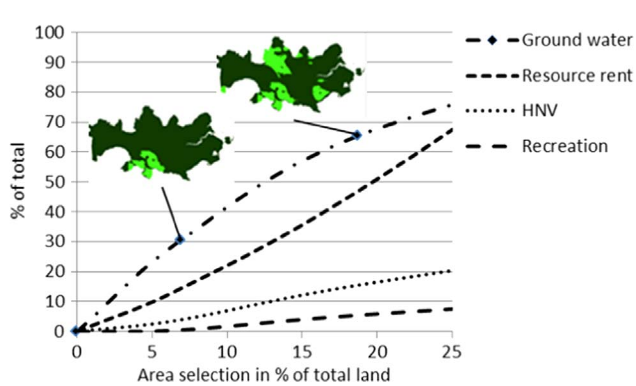

Fig. 7. Maximizing ground water interests.

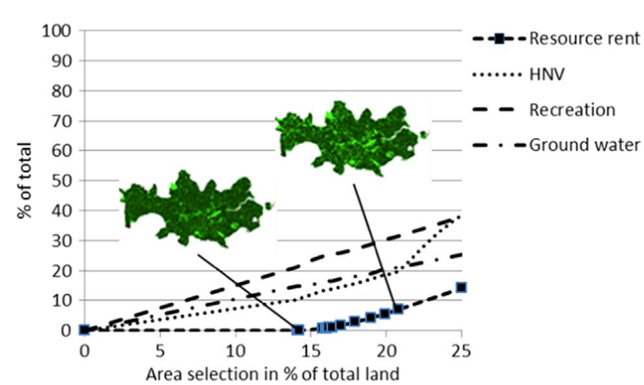

Fig. 9. Minimizing resource rent loss.

2006; Bennett et al., 2009; Maes et al., 2012).

Our results show the importance of defining the goal initially to the model iterations as the variation in weights might sustain other ecosystem services or goals better than expected. Being willing to change weights that could seem counter-intuitive is crucial in obtaining the goal (Chen et al., 2010; Store and Kangas, 2001). For instance, in our case area, maximizing importance on ground water interest yields large bulk areas that, though relatively expensive to convert, would have the potential to become some of the largest natural areas in the country if implemented. This option would probably be the most favorable in terms of securing robust nature in the long term on agricultural land though current HNV scores might not be of great magnitude.

Conversely, the scenario of maximizing nature values selects areas of greatest current HNV values, but overall performance of reaching the goal is less clear as connectivity is not explicitly handled. With increasing area selection the interconnectedness point is further achieved, however, robustness is not prevalent. Focusing on recreational activities with the given area buffer zones, interconnectedness is provided to some extent as buffer areas trailing rivers also provide important natural corridors and likewise often hold relatively little economic value. A recreational scenario could therefore be important in attaining synergies in the provision of ecosystem services. An iterative process between analyst and decision maker prior to decision is needed to fully inspect the abundant possibilities.

The strengths of the spatial MCDA is its ability to incorporate a wide range of factors into a structured decision making process. However, the method suffers when relevant data is not available or obtainable which is often the case with ecosystem services (Bateman et al., 2011). Relevant services in a Danish context that are not yet possible to factor in to the MCDA are pollination effects, forest's protection against wind pressure, flooding mitigation among other (Ravensbeck et al., 2013). Both synergies and conflicts between these services and the ones already in the analyses are expected to exist, however, the model does not account for this.

Connectivity within a future nature network is one of the main criteria to support biodiversity. Our model does not specifically account for this; however the four scenarios with their respective focus illustrates how interconnectedness is not a given feature. It would therefore be beneficial to factor in a connectivity score for each scenario or iteration of the model to better compare the various options. Being able to omit small scattered areas of the selection and focus instead on connecting and enlarging clusters would significantly improve the performance of the model.

The HNV Farming Index applied in this case study is the best spatial biodiversity data available and plays an important role in the model selection process. Though, it only concerns open land under cultivation. Some open land protected areas are not indexes and most importantly, forests do not figure at all. To incorporate nature values of forests we designed the model so that all forested areas corresponded to the highest possible HNV value. This is obviously a simplified approach and a detailed HNV Index for forests would further improve the model performance.

Recreational activities are also a strong focus and the assigned buffer zones around relevant sites in this study are one way of incorporating these interests. Detailed valuation studies and dynamic effects models of increased recreational opportunities would likewise be very valuable to the analysis.

7. Conclusion

Ecosystem services are becoming increasingly important in long term planning of land use across Denmark to improve societal welfare and mitigating climate change effects. The spatial multicriteria decision analysis approach, for instance as implemented in the software ILWIS, can be a beneficial tool in the decision making process. This paper exemplifies this in a setting where decision makers are faced with the challenge of establishing a nature network in a local Danish case securing more robust and interconnected nature areas.

The unavoidable trade-offs appearing in servicing many political interests are uncovered in this paper disclosing correlations and lack thereof visualizing discussion points for decision makers in establishing a nature network. The spatial multicriteria decision analysis model applied effectively heightens the discussion level, as countless options of area size and measures exist with the conflicting interests presented through the model analysis. The approach can prove a valuable tool in future policy making contributing to the EU biodiversity strategy and national monitoring and reporting systems on ecosystem services by 2020.

Great challenges still exist in mapping and quantifying ecosystem services needed in order to conduct ecosystem service valuation studies. Natural science knowledge gaps are a major obstacle still in assessing the effects of changes in land use for important outcome variables. This makes policy planning and evaluation challenging. Local specific characteristics vary greatly further adding uncertainty to the equation when relying on generic studies. The spatial MCDA approach offers a useful way of handling this uncertainty in the decision process by providing a systematic area selection based on the available and relevant spatial variables. The model outcome relies heavily on the set of weights used by the decision maker and/or relevant stakeholders. Given the inherent subjectivity and uncertainty associated with defining the set of weights, the spatial MCDA approach further offers a structured and systematic way of investigating trade-offs and consequences associated with using different sets of weights allowing for reevaluation of the different interests and priorities among stakeholders and decision makers.

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